

## REINFORCED CONCRETE STRENGTHENING BY USING GEOTEXTILE REINFORCEMENT FOR FOUNDATIONS AND SLABS

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### ABSTRACT

*This research aims to discover experimentally, the punching shear behavior of reinforced concrete slabs strengthening, by using geogrid mesh with different percentage of steel reinforcement ratio ( $\rho$ ), where the main parameter which adopted in the experimental program are the presence of geogrid mesh, steel reinforcement ratio and concrete compressive strength, where three type of concrete were utilized; normal strength concrete (NSC), high strength concrete (HSC) and reactive powder concrete (RPC). Fifteen slabs are made, five of each type of concrete in the same group, one of the slabs is without geogrid mesh and four strengthening with the geogrid, and the other four are different in steel reinforcement ratio ( $\rho$ ). The dimensions of slabs in the present work are (850x450x70) mm in length, width and thickness. The experimental results indicate that, in the presence of geogrid, there is an increase in ultimate load. This increase differs with the differentiator of steel reinforcement ratio ( $\rho$ ), continuously, until steel reinforcement ratio ( $\rho$ ) is reduced to (0.0026).*

**KEYWORDS:** Punching Shear, Cracks, Geogrid, RPC & HSC

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### INTRODUCTION

Flat plates are two-way concrete slabs, having uniform depths and transfer loads, directly to supporting columns without the aid of beams or capitals or drop panels. Flat plates can construct quickly due to their simple formwork and reinforcing bar arrangements. They need the smallest overall story heights to provide specified headroom requirements, and they give the most flexibility in the arrangement of columns and partitions [1]. Probably, the two greatest practical problems for these floor systems are the avoidance of unacceptable deflections and the punching shear failures around the columns [2]. There are many different levels of load sensitivity for each structural member. Concrete slabs are one of the most sensitive structural members during the construction process due to shear dependency. One of the most likely failure modes could be punching shear [3]. Punching shear failure of the slab is usually sudden and leads to a progressive collapse of the flat plate structures; therefore, caution is needed in the design of slabs and attention should be given to avoid the sudden failure condition [4]. There are two main ways to develop resistance to punching shear stresses, one deal with reinforcement pattern and thickness of slabs and another deal with the materials used to improve the resistance to punching shear. The way that deals with reinforcement and thickness is used as drop panels and column capitals [5, 6], conventional shear stirrups [7], shear head reinforcement [8, 6] and shear studs [8]. The other way it deals with, the material increases compressive

strength of concrete [Gardener [10] and Tuan [3]].

## EXPERIMENTAL PROGRAM

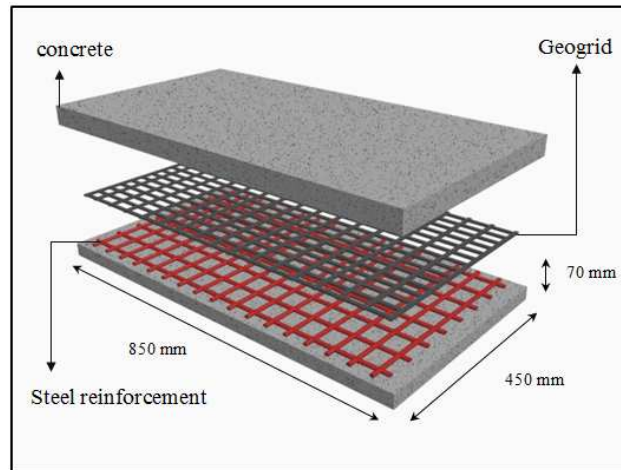
The main purpose behind the experimental program is to study the punching shear behavior of fifteen specimens of two way flat plate slab with geogrid mesh divided into three categories, according to cement type. Reactive Powder Concrete (RPC), High strength concrete (HSC) and conventional concrete (NSC) were cast and tested. Each group has five specimens, three of them different in Flexural steel reinforcement ratio ( $\rho$ ). The concrete slab section has been cast, then tested under a point load represent punching shear force by square steel column of dimensions (40x40) mm, one of each group was made without geogrid mesh, only flexural reinforcement which represents the reference and the others with both flexural reinforcement and geogrid mesh

## SPECIMEN'S DETAILS

Each test slab of the present investigation was rectangular with dimensions of (850x450x70) mm in length, width and thickness, respectively. The slab was simply supported along its four edges and loaded by a central steel column of dimension (40x40) mm. Four steel reinforcement ratios ( $\rho$ ) (0.01, 0.0052, 0.0026 and 0.0013) for each group were utilized in the research. The Table (1) presents details including the variety of testing slabs, while Figure 1 shows the details of slabs.

**Table 1: Details of Slabs Variables**

Group No.	Specimens	Type of Concrete	Steel Reinforcement Ratio ( $\rho$ )	Presence of Geogrid Mesh
G1	NS1	NSC	0.01	-
	NS1G		0.01	✓
	NS2G		0.052	✓
	NS3G		0.0026	✓
	NS4G		0.0013	✓
G2	HS1	HSC	0.01	-
	HS1G		0.01	✓
	HS2G		0.0052	✓
	HS3G		0.0026	✓
	HS4G		0.0013	✓
G3	RS1	RPC	0.01	-
	RS1G		0.01	✓
	RS2G		0.0052	✓
	RS3G		0.0026	✓
	RS4G		0.0013	✓



**Figure 1: Details of the Tested Slab**

## MATERIAL

In manufacturing test specimens, the following materials have been used:

Ordinary Portland cement type (I) Mass (Sulaymaniyah) in Iraq was used. Table (2) List the results of physical properties of the cement. Results indicate that the available cement conforms to the Iraqi Specification (IQS) No.5/1984 [11].

**Table 2: Physical properties of cement**

Physical Properties	Test Result	Limit of Iraqi Specification No.5/1984
Specific surface area (Blaine Method), $m^2/kg$	383	230 (min)
Setting time (Vicat's method)		
Initial setting, hrs: min	1:55	00:45 (min)
Final setting, hrs: min	4:25	10:00 (max)
Compressive strength, MPa		
3 days	25.85	15.00 (min)
7 days	28.00	23.00 (min)
Autoclave expansion %	0.01	0.8 (max)

## Fine Aggregate

Two types of fine aggregate, different in size were used in the present study. Al-Ekhaider natural sand of 4.75mm maximum size, was used as fine aggregate in the design mix of (HSC) and (NSC), and Very fine sand with maximum size 600 $\mu m$  was used for (RPC) Mix. The grading of used fine sand conforms to the Iraqi specification (IQS) No.45/1984 [12]

## Coarse Aggregate

Crushed gravel from AL-Nibaey region was used for modified reactive powder concrete (MRPC) mixes with a maximum size of 5mm. This crushed gravel was washed, then stored in air for surface drying, and then stored in a saturated surface dry condition before using.

## Silica Fume

The silica fume ( $SiO_2$ ) reacts with this calcium hydroxide to form an additional binder material (calcium silicate

hydrate (C-S-H)) which is very similar to the calcium silicate hydrate, formed from the Portland cement [13]. In the present paper, Silica fume has (20%), cement mass for (RPC). The chemical composition of this silica fume conforms to the ASTM 1240-04 [13]. High range water, reducing agent HRWRA) based on poly carboxylic ether is used. One of the new generation of polymer based super plasticizer Glenium 51 is used, the normal dosage for is (0.5-0.8) L/100kg of cement mass. It is free from chlorides and complies with ASTM C494 [14] types A and F.

### Steel Fibers

Hooked end short steel fibers were used in this work with volume fractions of ( $V_{sf}=1\%$ ). The properties of the used steel fibers are shown in Table (3).

**Table 3: Properties of Steel Fiber**

Property	Specifications
Relative density	7860 kg /m <sup>3</sup>
Yield strength	1130 MPa
Modulus of elasticity	200x10 <sup>3</sup> MPa
Strain at portion limit	5650x10 <sup>-6</sup>
Poisson's ratio	0.28
Average length	32 mm
Nominal diameter	0.4 mm
Aspect ratio( $L_f/D_f$ )	80

### Steel Reinforcement

Deformed steel bars of nominal diameter (6) mm have been used as flexural reinforcement placed in the tension face of the slab (at bottom). Bars have been tested in the material laboratory of the Civil Engineering Department at Al-Mustansiriyah University, test results of steel bars conform to (ASTM A615/615M-13) [15], the results listed in Table (4).

**Table 4: Properties of Steel Bars**

Nominal Diameter (mm)	Measured Diameter (mm)	Modulus of Elasticity ( $E_s$ ) (GPa)	Yield Stress( $f_y$ ) (MPa)	Ultimate Stress( $f_u$ ) (MPa)
6	6.17	200	420	620

### Geogrid

Geogrid used in this research was geogrid Tensar SS2, manufactured by the British Company Netlon Ltd, type of structure, rib dimensions, junction type, aperture size, and thickness shown in Table (5). The mechanical properties of this type of geogrid are summarized in Table (6).

**Table 5: Physical Properties of Tensar SS2 Geogrids**

Property	Unit	Data
Standard Color	-	Black
Polymer Type	-	High Density Poly Ethylene, HDPE
Packing (Length/Width)	m	Rolls (50/4)
Aperture Size (MD/XMD)	mm	28/40
Mass per Unit Area	Kg/m <sup>2</sup>	0.3
Rib Thickness	mm	1.2/1.1
Junction Thickness	mm	3.9
Longitudinal Rib Width	mm	3
Transverse Rib Width	mm	3

**Table 6: Mechanical Properties of Tensar SS2 Geogrids**

Property	Unit	Data
Peak Tensile Strength MD/XMD	kN/m	14.4/28.2
Elastic Modules MD/XMD	GPa	0.57/0.99
Upper Yield Strength MD/XMD	MPa	1/3
Lower Yield Strength MD/XMD	MPa	1/3
Tensile Strength MD/XMD	MPa	24/30.7
Fracture Percentage Elongation MD/XMD	%	-98/-98
Percentage Elongation at Maximum Load MD/XMD	%	3.5/2.9

Clean tap water was used for both, mixing and curing. Table (7) gives mix proportions of the three types of concrete (NSC, HSC and RPC).

**Table 7: Mix Proportions of Concrete**

Type of Concrete	Cement kg/m <sup>3</sup>	Sand kg/m <sup>3</sup>	Gravel kg/m <sup>3</sup>	Silica Fume* %	Silica fume kg/m <sup>3</sup>	w/c	Superplasticizer (L/m <sup>3</sup> )	Steel fiber content** %	Steel Fiber Content kg/m <sup>3</sup>
NSC	400	600	1200	—	—	0.45	—	—	—
HSC	510	590	1000	0.32	—	0.32	5	—	—
RPC	1000	1000	—	20	200	0.2	5	1	78

### Mixing Procedure

In this study, mixing was performed by using 0.19 m<sup>3</sup> capacity horizontal rotary mixer. Before using the mixer, the remaining concrete from previous batch was cleaned off. A damp cloth was used to wipe the pan and the blades of the mixer and all quantities weighted and packed in a clean container.

### NSC and HSC Mixing

Firstly, dry sand is loaded into the mixer and then add a 0.5L of water for moistening the sand, after that, gravel is mixed for 0.5 minutes with sand. Then cement added to the mixer and all dry material are mixed for 1 minute to ensure the homogeneity of the mixture. Water adds after that in three stages and mixed for (3) minutes. Then, the mixing process is stopped to shovel the mix by hand and then restarted for (3) minutes. This step is for homogeneity of the mix. For HSC the procedure of mixing is similar to NSC mixing except that the super plasticizer (Glenium 51) was used and divided into three doses and mixed with the water.

### RPC Mixing

Dry materials (cement, silica fume, fine sand) are mixed, firstly silica fume and cement are mixed for (15) minutes to ensure that, thoroughly dispersed, the fine sand is loaded into the mixer and mixed for (3) minutes. Then, the super plasticizer (Glenium 51) is added to the water and mixed together, then added to the rotary mixer and the whole mix ingredients are mixed for a sufficient time. Then, the mixing process is stopped to shovel the mix by hand and then restarted for (3) minutes. This step is the homogeneity of the mix, after the third cycle steel fiber is added to the wet mix by hand while mixing is rotated for (3) minutes. The total time of mixing is 25 minutes.

### Casting, Compacting and Curing Procedure

The molds are cleaned and their internal surfaces are oiled to prevent adhesion to concrete after hardening and placed the spacers to provide a cover with (10 mm) thickness, reinforcement steel mesh was placed near the bottom face of

the slabs. The concrete was placed in the mold in three equal layers. Each layer was compacted by using an electrical vibrating table for two minutes. The slab was covered with polyethylene sheets to prevent moisture loss. Figure 2 shows the details of casting.



**Figure 2: Details of Casting**

After 24 hours of casting, the specimen and control specimens (cubes, cylinder, prism) are removed from their molds and placed in a container, filled with tap water with temperature about ( $25^{\circ}\text{C}$ ) until the testing age of (28 days)

### Test Procedure

Setup of testing specimens is shown in Figure 3. All slab specimens were tested using a universal testing machine (MFL system) with monotonic loading to ultimate states. The tested slabs were simply supported and loaded with a single-point load. The slabs have been tested at the ages of (28) days. The slab specimens were placed on the testing machine and adjusted so that the centerline, supports, point load and dial gauge were in their correct or best locations. Loading was applied slowly in successive increments; the applied load is transformed from testing machine through a central steel cube of dimensions (40x40mm). At the end of each load increment, observations and measurements were recorded for the mid-span deflection and crack development and propagation on the slab surface. When the slab reached an advanced stage of loading, smaller increments were applied to failure, where the load indicator stopped recording anymore and the deflections increased very fast without any increase in applied load. The developments of cracks (crack pattern) were marked with a pencil at each load increment.



Figure 3: Punching Shear Test of Reinforced Concrete Slabs

## RESULTS AND DISCUSSIONS

### Control Specimens

Table (8) shows the mechanical properties of (RPC), (HSC) and (NSC).

Table 8: Mechanical properties for (NSC), (HSC) and (RPC)

Type of Concrete	Cylinders Compressive Strength $f'_c$ (MPa)	Cubes Compressive Strength $f_{cu}$ (MPa)	Modulus of Elasticity $E_c$ (GPa)	Splitting Tensile Strength $f_{sp}$ (MPa)	Modulus of Rupture $f_r$ (MPa)
NSC	31.3	35	27.3	3.96	4.6
HSC	50.67	61	29.64	4.8	7
RPC	127	149	50	14.7	24.16

### Slab Specimens

#### General Behavior

Generally, as the load increase, radial cracks start to appear and extend from that perimeter toward the slab edges. At the same time, the cracks increase in number in the center region of the slab. A complete failure occurred with increasing the load.

#### Ultimate and Cracking Loads

In the three groups, the first crack for each specimen is more than the value for the reference slabs, although the steel reinforcement ratio decrease and this due to the presence of the geogrid mesh. The largest increase in the first crack value was in the 2<sup>nd</sup> specimen for each group by (85.7, 126.5 and 87.5) % of their references for (NS1, HS1 and RS1) respectively. The 2<sup>nd</sup> specimen in each group had the highest value by (138.23, 101.7 and 62) % from their reference for (NS1G, HS1G AND RS1G) respectively, and this due to the combination between geogrid mesh and highest percentage of ( $\rho$ ). In each group, for specimen 3<sup>rd</sup> and 4<sup>th</sup> with decreasing the ( $\rho$ ) to become about (50) % and (25) % from ( $\rho_1$ ) the ultimate load increase by (41, 17.6) % for (NSC) and (21.35, 11.8) % for (HSC) and (17.4, 4) % for (RPC), this shows that despite the reduced in ( $\rho$ ), there is an increase in punching shear strength due to the role of geogrid mesh. As the compressive strength increase the average increase in ultimate load in (HSC) and (RPC) is (59.6 and 43) % of (NSC), respectively. For the last specimen in each group, with decreasing the ( $\rho$ ) to about (12.5) % of ( $\rho_1$ ) the ultimate load decrease by (11.76) %, (5) % and (5.5) % of their references for (NS4G), (HS4G) and (RS4G) respectively. Test results are



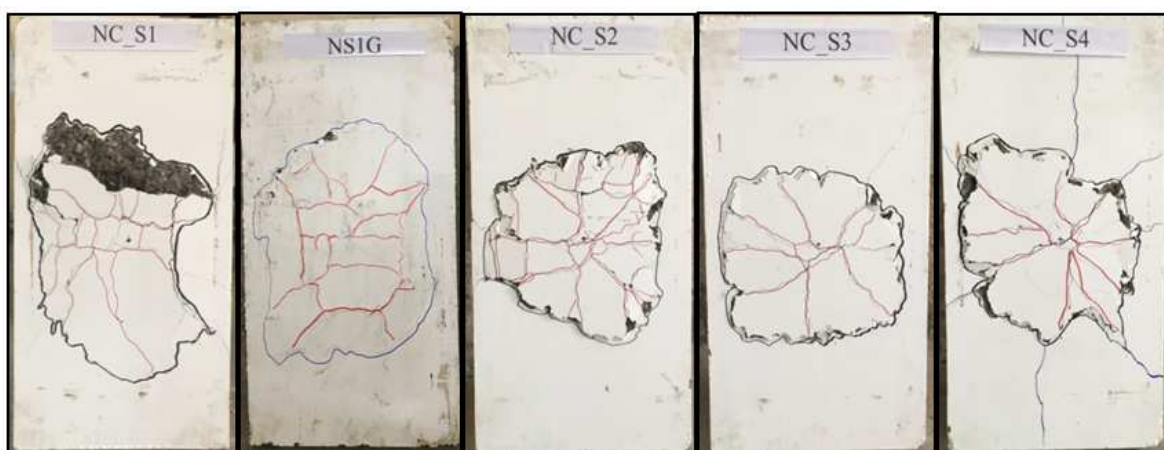
given in Table (9) and Photographs of the tested slabs are shown in Figure 4

**Table 9: Ultimate, Cracking Load and Type of Failure of Tested Slabs**

Group No.	Specimens	First Crack Load ( $P_{cr}$ ) (kN)	$\frac{P_{cr}}{(p_{cr})R}$	Ultimate load ( $P_u$ ) (kN)	$\frac{P_u}{(p_u)R} \%$	$\frac{P_{cr}}{(p_u)} \%$	Mode of Failure
1	NS1	17.5	-	85	-	20.6	Punching
	NS1G	32.5	185.7	202.5	238.23	16	Punching
	NS2G	28	160	120	141	23.3	Punching
	NS3G	25	142.8	100	117.6	25	Punching
	NS4G	15	85.7	75	88.23	20	Punching+ flexural
2	HS1	32	-	147.5	-	21.7	Punching
	HS1G	72.5	226.5	297.5	201.7	24.36	Punching
	HS2G	55	171.8	179	121.35	30.7	Punching
	HS3G	50	156.25	165	111.8	30.3	Punching
	HS4G	40	125	140	95	28.57	Punching+ flexural
3	RS1	48	-	230	-	20.8	Punching
	RS1G	90	187.5	372.5	162	24.16	Punching
	RS2G	76	158.3	270	117.4	28.15	Punching
	RS3G	70	145.8	239	104	29.2	Punching
	RS4G	59	123	217.5	94.5	27	Punching+ flexural

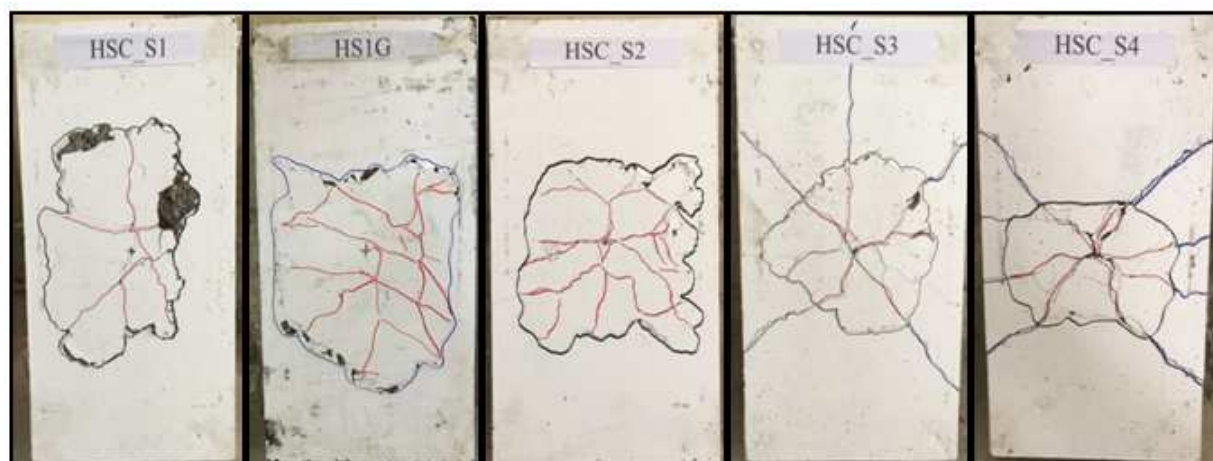
### Failure Mode and Crack Pattern

Generally, The slab specimens are filled in punching shear, except the specimens with ( $\rho = 0.0013$ ) the mode of failure convert from punching failure to composite (Punch+ flexure) failure, and this is due to the decrease in the steel reinforcement ratio. The first crack appears around the zone of the applied load column on the tension face of the slab. By increasing the load, these cracks widen and increase in number. As the concrete's compressive strength increases, it is observed that the cracks transfer gradually from the elliptical shape of the circular and became less in number and much finer. It is observed that specimens which strengthen by geogrid mesh, did not happen falling parts of concrete cover, as it happened in references slabs.

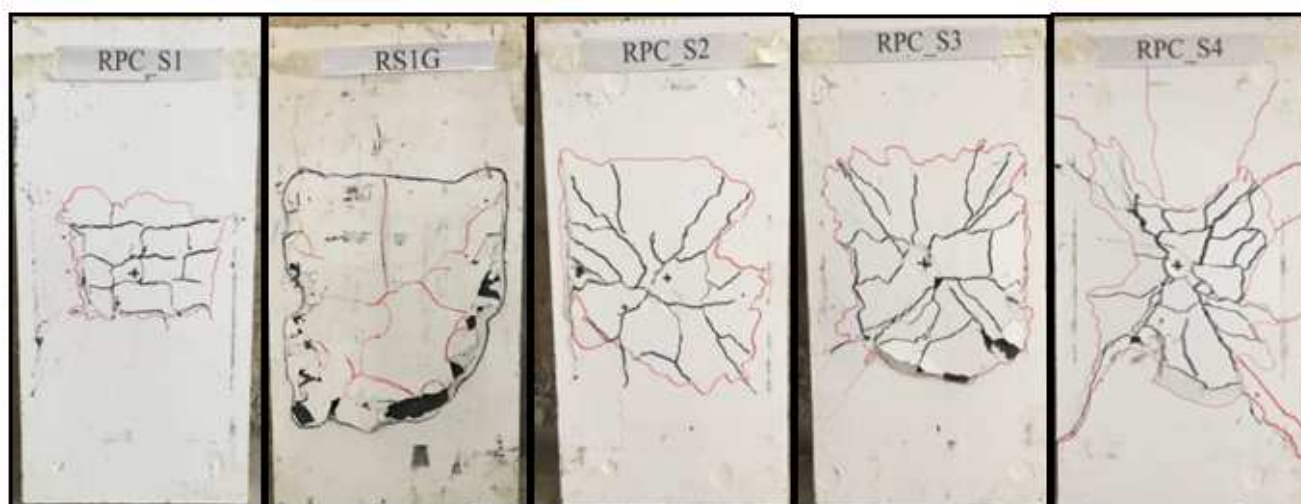


**Group (NSC)**





Group (HSC)



Group (RPC)

Figure 4: Cracks Pattern of Tested Slabs at Failure

### Load – Deflection Behavior

Figure 5, 6 and 7 shows the central load-deflection curve for all tested slabs of each group to illustrate the general behavior of these specimens.

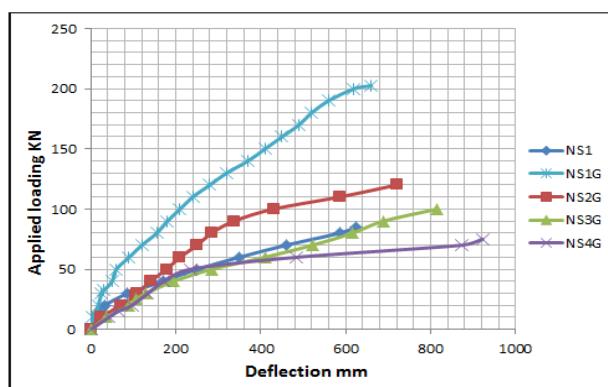


Figure 5: Load – Deflection Curve of group 1 (NSC)

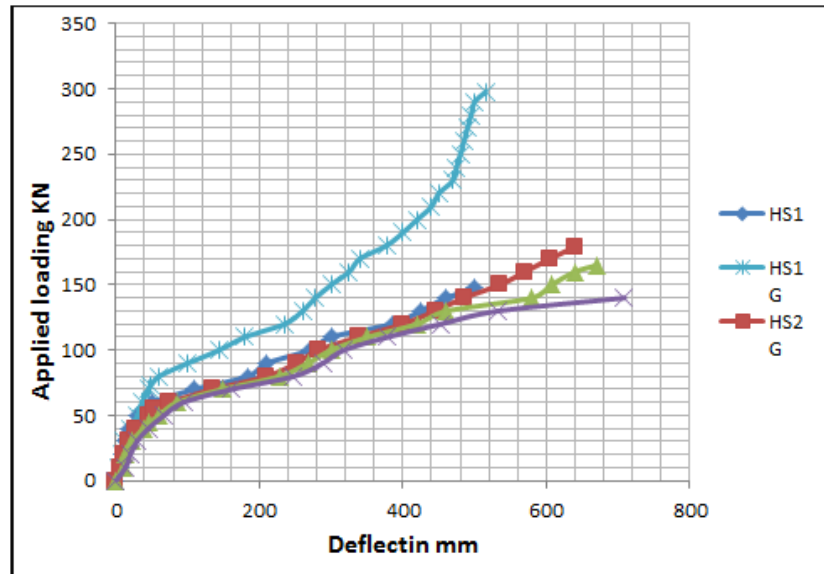


Figure 6: Load – Deflection Curve of group 2 (HSC)

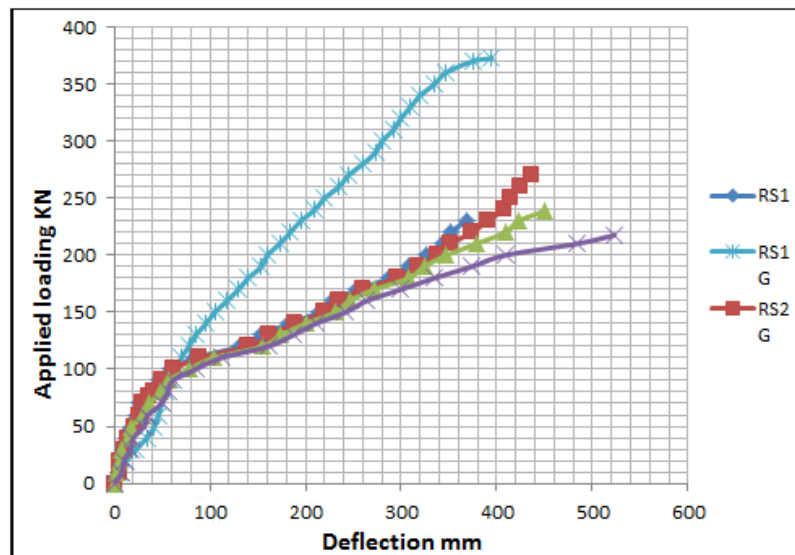


Figure 7: Load – Deflection Curve of group 3 (RPC)

The percentage of increase in deflection in specimens (NS1G, NS2G, and NS3G) were (5.6, 15.2, 30.4) % and by (3, 28, 34) % for (HS1G, HS2G and HS3G) and (7.3, 18.75, 22.5) for (RS1G, RS2G and RS3G), respectively from reference specimens. This shows that the deflection increase with decreasing the ( $\rho$ ). Despite the increase in the deflection in the specimens with decreasing the ( $\rho$ ), however, there is an increase in the ultimate load capacity except the 5<sup>th</sup> specimen in each group. For the 2<sup>nd</sup> and 3<sup>rd</sup> group, the average increase in the deflection for the specimens in the same group are little, and this is due to the effective role of the high value of compressive strength which reduces the effect of decreasing the ( $\rho$ ), in comparison with the 1<sup>st</sup> group.

## CONCLUSIONS

According to the results of this experimental study, the following conclusions were drawn:

- Use of geogrid mesh shows good effect in increasing the ultimate load capacity with the same steel reinforcement

ratio and concrete compressive strength, in the second specimens, in each group by (138.23, 101.7 and 62) % for NS1G, HS1G and RS1G as compared with their reference, respectively.

- By decreasing the steel reinforcement ratio to ( $\rho = 0.0013$ ), the effectiveness of geogrid became less than the effect of steel reinforcement. This shows that it cannot depend mainly on geared only, in reinforcement.
- Using geogrid enhances the first cracks in the three groups, for each specimen by (42.8-85.7) % for NSC, (25-126.5) % for HSC and (23-87.5)% for the RPC as compared with their reference, respectively.
- Deflection is increased in specimens in the same group, respectively from one to another, and this is due to two reasons; the first, result of the presence of geogrid where, when compared first slabs with the second, in each group with the constant value of ( $f'_c$ ) and ( $\rho$ ), there is a slightly increase in the deflection and this result to effect of the geogrid, as well as increase in the ultimate load capacity. While the second reason is, decreasing the steel reinforcement ratio as in slabs No. 3, 4 and 5 in each group. When comparing the values of the deflection between the three groups, it is clear that there is a decrease in the deflection and results to the effect of concrete's compressive strength.

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